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XIII. *Observations on the Annual Evaporation at Liverpool in Lancashire; and on Evaporation considered as a Test of the Moisture or Dryness of the Atmosphere. By Dr. Dobson of Liverpool. Communicated by John Fothergill, M. D. F. R. S.*

Read Feb. 13, 1777. **T**HE quantity of rain which falls during

the course of the year, is a very uncertain test of the moisture or dryness of any particular season, situation, or climate. There may be little or even no rain, and yet the air be constantly damp and foggy; or there may be heavy rains, with a comparatively dry state of the atmosphere. The same depth of rain will likewise produce different effects on the air, according as it falls upon a flat or hilly country; for large quantities soon quit the hills or high grounds, while smaller quantities have more lasting and powerful effects on a flat country. Much also depends upon the nature of the soil, whether clay or sand, whether firm and compact, or loose and spongy.

Is not evaporation therefore a more accurate test of the moisture or dryness of the atmosphere, than the quantity of rain?

It

It is well known, that air is an active solvent of water, and that its powers of solution are in proportion to its dryness. It is likewise well known, that in chemical solutions, the action of the *menstruum* is greatly promoted by heat and agitation. If the temperature of the air then, and the state of the winds, be ascertained, which in the present case denote the heat and agitation of the *menstruum*, the evaporation will be the true index of the dryness of any particular season, situation, or climate.

To determine the annual evaporation in the neighbourhood of Liverpool, I procured two well-varnished tin vessels; one of which was to serve the purpose of a rain-gage; the other was to be employed as my evaporating vessel. The evaporating vessel was cylindrical, twelve inches in diameter and six inches deep. The rain-gage consisted of a funnel twelve inches likewise in diameter, the lower end of which was received into the mouth of a large stone-bottle; and, to prevent any evaporation from the bottle, the pipe of the funnel was stopped with a grooved cork. These vessels were placed in the middle of a grass-plot, on a rising ground adjoining and immediately overlooking the town, about seventy-five feet above the level of the sea, and with a free exposure to the Sun, winds, and rain. The cylindrical vessel was filled with water within two inches of the  
top;

top; and if, in consequence of heavy rains, there was danger of its overflowing, a quantity of water was taken out; but if, in consequence of long drought, it sunk lower, a quantity of water was then occasionally added; and these additions or subtractions were carefully registered. At the end of every month, the depth of rain was first calculated; and, as each vessel received the same depth of rain, I had only to examine the quantity of water which had been added to, or taken out of, the evaporating vessel, and the evaporation of the month was ascertained.

The first column of the following tables points out the mean temperature of the air at two in the afternoon. The second, the character of the month with respect to the winds, the number of dots expressing their strength; and, to make this part tolerably accurate, daily observations on the winds were marked down, and the character of the month formed from a general survey of these observations: our winds are Westerly for near two-thirds of the year. The third column points out the evaporation of each month in inches and decimal parts of an inch. The fourth, the depth of rain during each month. And the fifth, the state of the seasons, E being prefixed to the evaporation of the whole three months, R to the rain, and T to the mean temperature. I

It is to be observed, that in making these experiments, 251 grains were allowed for every cubic inch of water; and that three pounds and twelve ounces of water give a depth of one inch on a circular area of twelve inches diameter.

T A B L E I.

A comparative view of the evaporation, rain, winds, and temperature of the air, during the year 1772.

Months.	Temp.	Winds.	Evaporat.	Rain.	Seasons.
January	38	. . .	1.27	3.26	} E. 4.87 R. 7.23 T. 40.
February	39	. . . .	1.25	2.35	
March	44	. . .	2.35	1.62	
April	48	. .	4.53	1.85	} E. 11.40 R. 8.39 T. 57.
May	57	.	4.25	3.42	
June	67	. .	4.62	3.12	
July	70	. .	5.53	1.59	} E. 13.20 R. 11.29 T. 66.
August	68	. .	5.35	3.65	
September	62	.	2.32	6.05	
October	60	. .	3.18	3.42	} E. 6.46 R. 10.48 T. 51.
November	50	. . .	2.15	4.85	
December	44	. .	1.13	2.21	
	54		35.95	37.39	

T A B L E II.

A comparative view of the evaporation, rain, winds, and temperature of the air, during the year 1773.

	Temp.	Winds.	Evaporat.	Rain.	Seasons.
January	44	....	1.85	3.15	} E. 5.74 R. 6.17 T. 45.
February	42½	...	1.13	2.37	
March	50	...	2.76	0.65	
April	54	...	2.89	2.47	} E. 9.34 R. 8.35 T. 58.
May	57	..	3.79	4.56	
June	64½	.	2.66	1.42	
July	67	..	4.92	1.32	} E. 14.02 R. 10.08 T. 65.
August	70	.	5.75	2.21	
September	60	..	3.35	6.55	
October	55	...	2.79	4.57	} E. 5.49 R. 15.58 T. 48.
November	47½	...	1.15	6.69	
December	41½	...	1.55	4.32	
	54½		34.59	40.18	

T A B L E III.

A comparative view of the evaporation, rain, winds, and temperature of the air, during the year 1774.

	Temp.	Winds.	Evaporat.	Rain.	Seasons.
January	37	. . .	1.38	4.43	} E. 5.92 R. 8.23 T. 44.
February	45 $\frac{1}{2}$	. . . .	1.67	2.42	
March	49 $\frac{2}{3}$	. . .	2.87	1.38	
April	54 $\frac{1}{2}$	. . . .	4.56	2.23	} E. 12.39 R. 7.14 T. 59.
May	59 $\frac{1}{2}$	. . .	4.31	1.65	
June	63	. .	3.52	3.26	
July	66 $\frac{2}{3}$	. . .	4.97	2.68	} E. 13.51 R. 10.56 T. 65.
August	67	. .	4.52	2.36	
September	61 $\frac{1}{3}$	. .	4.02	5.52	
October	57	. .	1.95	1.68	} E. 4.82 R. 6.00 T. 48 $\frac{1}{2}$ .
November	46 $\frac{1}{3}$	. . .	1.12	2.69	
December	41 $\frac{3}{4}$	. .	1.75	1.63	
	54		36.64	31.93	

TABLE IV.

A comparative view of the evaporation, rain, winds, and temperature of the air, during the year 1775.

	Temp.	Winds.	Evaporat.	Rain.	Seasons.
January	44½	...	1.51	3.21	} E. 7.10 R. 10.28 T. 47½.
February	49	....	3.02	4.62	
March	48½	...	2.57	2.45	
April	57½	...	3.21	1.01	} E. 15.09 R. 3.98 T. 63.
May	61	...	5.02	0.85	
June	70½	...	6.86	2.12	
July	68½	..	5.03	5.31	} E. 12.50 R. 12.57 T. 56½.
August	66½	..	4.42	4.26	
September	65	..	3.05	4.00	
October	54½	...	2.12	7.01	} E. 5.27 R. 13.39 T. 49½.
November	45	..	1.63	3.03	
December	48½	..	1.52	3.35	
	54		39.96	40.22	

## OBSERVATIONS.

1. It is evident from these tables, whether we attend to separate months, seasons, or years, that the depth of rain is a very erroneous index of the moisture or dryness of the atmosphere. On comparing the two months July and August of the year 1772, it appears that the temperature

perature of the air, the state of the winds, and the evaporation, were nearly the same during these two months, and yet the rain of August was more than double that of July. The reason why the greater quantity of rain had no more effect than the smaller in adding moisture to the atmosphere, is obvious; for on consulting my register I find, that the rain of August fell in heavy showers, and ran off the ground before it could be evaporated; while that of July, falling in small drizzling showers, gave more time for its evaporation.

Again, the temperature of the air, the state of the winds, and the evaporation, were nearly the same during the first three months of the year 1773, with what they were during the last three months of that year; the state of the air therefore, with respect to moisture and dryness, must have been the same during these two seasons; and yet the depth of rain, in one of these seasons, was much more than double what it was in the other. If we attend to whole years the same observation is confirmed. The rain of 1775 exceeded the rain of 1774 more than eight inches; and hence it might be concluded, that the atmosphere was more moist in 1775 than in 1774; the reverse of this, however, is found to be the fact: for there evaporated from a constant and determinate surface of water in 1775, full three inches more

than evaporated from the same surface of water in 1774. Consequently the dryness of the atmosphere or its power of solution, during the year 1775, exceeded that of 1774.

2. If we take the medium of four years observations it appears, that the annual evaporation at Liverpool amounts to 36.78 inches.

Dr. HALLEY observed at London, that water placed in a close room, where neither the winds or Sun could act upon it, exhaled only eight inches during the whole year. He makes no doubt but that the free access of the winds would have trebled the quantity carried away; and that this again would have been doubled by the assistance of the Sun. Dr. HALLEY, therefore, fixes the annual evaporation of London at 48 inches <sup>(a)</sup>. If this calculation be admitted, it follows, that the annual evaporation of London exceeds the annual evaporation of Liverpool 11 inches; but were the experiments to be made in London, in the same circumstances with those made at Liverpool, it is probable, that this would be found to be more than the real difference.

The learned CRUQUIUS observed at Delft in Holland, that there exhaled from water set in the open air, but in a calm and shady place, about 30 inches; and it is not to

(a) Phil. Trans. N<sup>o</sup> 212.

be doubted, says Dr. BROWNRIGG in his very valuable work, *The Art of making common Salt*, but that double this quantity, or 60 inches, would have exhaled, had it been placed where the Sun and winds could have had their due effects <sup>(b)</sup>. In another part of this publication, Dr. BROWNRIGG fixes the evaporation of some parts of England at 73.8 inches during the four summer months, May, June, July, and August; and the evaporation of the whole year at upwards of 140 inches <sup>(c)</sup>. These are calculations, however, which do not appear to correspond with experience; for the whole evaporation at Liverpool, instead of 140 inches, was only 36.78 inches. The evaporation likewise of the four summer months, on a medium of four years, instead of 73 inches, was only 18.88 inches.

3. Dr. HALES calculates the greatest annual evaporation from the surface of the earth in England, even that from a surface of hop-ground, at 6.66 inches <sup>(d)</sup>. If we compare this with the annual evaporation from a surface of water as determined by experiment, we find, that the latter exceeds the former about 30 inches; and that the annual evaporation from a surface of water, is to the annual evaporation from the surface of the earth in this part of England, nearly as 36 to 6, or as 6 to 1.

(b) Page 185.

(c) P. 189.

(d) Veg. Stat. vol. I. p. 55, 56.

4. On comparing the depth of rain with the annual evaporation of this part of Lancashire we find, that more falls in rain than is raised in vapour, even though the whole were a surface of water; for the rain is to the evaporation as 37.43 inches to 36.78 inches: and we farther find, that the quantity exhaled from the surface of the earth is little more than a sixth part of what descends in rain; we must therefore have very large supplies from other regions, from the surrounding sea, and from the ocean of warmer climates: Hence we see, why our South and South-west winds are so often accompanied with rain; for as the air sweeps along the warmer latitudes, it involves a large proportion of moisture, which is constantly and copiously exhaling from the ocean; and this moisture being retained in a state of solution till it reaches the colder climates, is then either collected in clouds or immediately precipitated in rain, according to the different conditions of the atmosphere.

These foreign supplies, however, are uniformly restored to the sources from which they were derived: for that proportion of rain which rises not in vapour, after moistening and refreshing the earth, forms springs, brooks, and rivers, and is thus perpetually returning to the ocean whence it was taken; so truly philosophical are the words of the preacher when speaking of this vast circulation:

circulation: "All the rivers run into the sea, yet the sea  
"is not full: unto the place from whence the rivers  
"come, thither they return again."

5. About a century ago, the ingenious Mr. TOWNLEY, of Townley in this county, made some accurate observations on the depth of rain which fell annually in the neighbourhood of the hills which divide Lancashire and Yorkshire; and on taking a medium of fifteen years, he determines it to be 41.516 inches<sup>(e)</sup>. The depth of rain, therefore, at Townley exceeds the depth of rain at Liverpool about four inches. This is probably, however, less than the real difference; for there was a source of error in Mr. TOWNLEY's experiments with which the world was not at that time acquainted. Mr. TOWNLEY's rain-gage was fixed full ten yards above the surface of the earth<sup>(f)</sup>; which circumstance, according to some later observations, makes a very material difference in the result of the experiment<sup>(g)</sup>. Were the observations to be repeated at Townley, and the rain-gage placed upon the ground, there can be no doubt but that the depth of rain would considerably exceed 41.516 inches; for I find from a great number of experiments, made during the last three

(e) Phil. Transf. abridged by Lowthorp, vol. II. p. 46.

(f) Ibid.

(g) Phil. Transf. vol. LIX. art. 47.

years with two veffels of equal dimenfions, one placed on the ground, and the other eighteen yards higher on the battlement of the hofpital; that the quantity received in the lower veffel exceeds that in the higher more than one-third and lefs than one-half.

6. An ingenious friend, on perufing thefe obfervations, asked, “ Whether the fact of evaporation going on “ equally well in an exhausted receiver, was not an unfurmountable objection to that theory concerning evaporation, which fuppofes a chemical folution of water “ in air?” With a view to afcertain this fact I made the following experiment.

Two china faucers, each containing three ounces of water, were accurately weighed. One of them was placed in the open air; the quickfilver in the thermometer flood during the experiment between  $48^{\circ}$  and  $50^{\circ}$ , the day tolerably clear with a moderate breeze. The other was put under the receiver of an air-pump; the air was exhausted, and the piftons occafionally worked, to draw off any of the water which might be fuppofed to be converted into vapour. After four hours the faucers were again accurately weighed; that in the open air had loft one drachm and eight grains; the weight of the other was not fenfibly diminished.

From

From this experiment it appears, that air is a chemical solvent of water, and as such is undoubtedly to be considered as one cause of the evaporation of water. Heat is another cause of evaporation, and when raised to a sufficient degree may produce this effect without the intervention of air, and the evaporation consequently go on copiously in an exhausted receiver, agreeably to the experiments of the ingenious Dr. IRVING<sup>(i)</sup>.

The following observations are added as a farther illustration of this subject. Water may exist in air in three different states. 1. In a state of perfect solution. 2. In a state of beginning precipitation. Or, 3. Completely precipitated, and falling in drops of rain.

In the first instance, where the water is in a state of perfect solution, the air is clear, dry, heavy, and its powers of solution still active, though it already contains a considerable proportion of water. In the second, the air becomes moist, foggy, its powers of solution are diminished, and it becomes lighter in proportion as its water is deposited. It is a singular and well-attested fact, that it never rains in the kingdom of Peru; but that during part of the year the atmosphere is constantly obscured with

(i) Phipps's Voyage to the North Pole, p. 211.

vapours, and the whole country involved in what they call *Garuas*, or thick fogs <sup>(i)</sup>.

It is not necessary to point out the causes which thus dispose the air to deposite its dissolved water; nor to consider with what bodies air hath a stronger affinity than with water; neither to inquire how far the electrical fluid is engaged in the process. It is sufficient to observe, that so long as these causes have a general action on the air, they diminish its power of solution, and give a damp and foggy state of the atmosphere; that when they operate for a considerable proportion of the year, they produce a moist climate; and that when they more generally do not, and the air retains its moisture in a state of perfect solution, the climate is dry. Consequently, that the moisture or dryness of a climate, do not so much depend upon the absolute quantity of water which is contained in the air, as upon the air being in a state of perfect or imperfect solution. During long continued summer droughts, a very large proportion of water is dissolved in the air; notwithstanding this, the air is still dry, and continues to be so as but as the water remains in a state of perfect solution; long no sooner are the powers of solution diminished, than what was before a dry, now becomes a moist climate.

(i) D'Ulloa's Voyage to South America, vol. II. p. 69.

In the third instance, the dissolved water may be either slowly precipitated and fall in drizzling rain, or it may be more powerfully discharged in brisk rain; or there may be partial and sudden precipitations from particular regions, while other parts of the atmosphere still retain their water in a state of perfect solution. Heavy thunder-showers are the most remarkable instances of partial, sudden, and copious precipitations.

Liverpool, Nov. 20, 1776.

